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CRUISE MISSILE LAUNCH VEHICLE AUTOMATIC POSITIONING  
AND DIRECTION FINDING TECHNOLOGY

by

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ABSTRACT In the last 30 years, various nations of the world have developed and produced a series of military vehicle navigation systems. With a view to applications of automatic positioning and direction finding technology on cruise missile launch vehicles, the focus has been on discussions of the technical characteristics of GPS receivers and composite type guidance systems. Analysis has been done on applications of various foreign types of navigation systems to cruise missile launch vehicles, exploring the prospects for applications of automatic positioning and direction finding technologies on cruise missile launch vehicles.

KEY TERMS Missile launch vehicle Automatic positioning and direction finding GPS receiver Composite type navigation

## INTRODUCTION

Cruise missile launch vehicle automatic positioning and direction finding refers to the precise determination of the coordinates and directions associated with the location it is at before firing missiles. In order to increase the mobility of guided missile weapons systems, missile launch vehicles must possess the capability for fast automatic positioning and direction finding--even to the point of a capability for positioning and direction finding on the move--with the expectation of realizing "stop and shoot" even to the point of "move and shoot", increasing the survivability of missile weapons systems to the maximum extent.

In order to increase hit rates, launch vehicles must do precision positioning and direction finding. Precision requirements are not lower than for mobile howitzers. For example, the U.S. Patriot missile is one type of all weather, front line air defense missile system. The missile battalion is composed of a radar trailer and some launch vehicles. When introduced into combat, the vehicles are dispersed to several points, forming a relatively broad frontal air defense fan. At the appointed time--besides needing to know locations and directions associated with launch vehicles--it is also necessary to know the azimuths, ranges, and height differentials between the radar trailer and the various launch vehicles. With regard to missiles that are able to automatically navigate to targets, it is generally required that launch vehicles possess medium range positioning and direction finding precisions. However, between radar trailers and the various launch vehicles, relative positions and directions must reach very high precisions. Only then is it possible to make launch vehicles align on targets. As a result, launch vehicle automatic positioning and direction finding precisions must be very high. It is only then possible to satisfy requirements.

Launch vehicles on the march or in combat cannot get away from navigation instruments. Military vehicle navigation technology already has a development history of over 30 years. In the 1950's and 1960's, the former Soviet Union and the U.K. developed for the first time gyroscopic compasses for land use based on maritime navigation gyroscopic compasses. Finally, gyroscopic compass navigation systems achieved broad development in Germany. The types of products were very numerous. A number have already been exported abroad. Moving into the 1970's, the U.S. and the U.K. developed inertial navigation systems for land use based on aircraft inertial navigation systems. Using "pazi (phonetic)" position and direction determination systems as representative inertial guidance systems, it was just at this time that they appeared. At the present time, the U.S., the U.K., France, and even Israel all have their own units equipped with "pazi (phonetic)" position and direction determination systems. In the last few years, outside China, various types of quick connect inertial navigation systems have also been developed on the basis of missile quick connect type inertial guidance systems. Some systems have

already been successfully test manufactured and introduced into use. In 1993, the 24 satellites composing the GPS satellite constellation were already all in orbit. Moreover, GPS ground receivers have already been successfully developed in a number of nations. In 1991, the U.S. made use of them during the Gulf War. Positioning precisions were extremely high. Due to the production of GPS receivers for land use, various sorts of composite type land navigation systems carrying GPS receivers have also been appearing incessantly. In a number of countries, land navigation systems have already become serialized products, equipping numerous types of vehicles such as self-propelled guns, target detection vehicles, air defense missile systems, navigation broadcast vehicles, supply vehicles, command vehicles, as well as observation vehicles, and so on. Below, we will primarily introduce foreign vehicles making use of GPS receivers and composite navigation systems.

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## 1 GPS

In 1991, during the Gulf War, the U.S. Army made use of GPS systems for the first time in actual combat. During the war, the systems in question played important roles in navigation and positioning of multinational units. As a result, after the war, the U.S. Army put forward a series of new requirements with regard to these systems. Among them were included missile launch vehicles, combat vehicles, tanks, and mobile command posts equipped with them and opting for the use of GPS receivers in order to increase weapons system and unit rapid reaction capabilities as well as maneuver capabilities. Such nations as Germany, the U.K., and France vigorously developed GPS application technologies. A number of GPS composite land navigation systems already equip units.

### 1.1 Brief Introduction to GPS

GPS systems are composed of three parts--navigation satellites, ground control stations, and user receivers.

Navigation satellites are made up of 21 operational satellites and 3 reserve satellites. Operational satellites are uniformly distributed in 6 polar orbits. Mean orbital altitude is 20200km. They go around the earth once every 12 h. Each satellite continuously transmits accurate time and navigational information.

Ground control portions are made up by 1 central control station, 3 input stations, and 5 monitoring stations. They are responsible for such tasks as satellite monitoring, processing of various items of information, transmission, parameter calculation, and so on.

User equipment is primarily made up by GPS receivers, data processing software, microprocessors (unclear), as well as the terminal equipment.

Basic GPS calculation techniques are to accurately determine time delays from satellite transmitters to GPS receivers. After that, celestial positions for each satellite are calculated out, giving the position when satellites send out each data byte. Going through 4 satellites, receivers are capable of obtaining three

dimensional position and three dimensional velocity data.

As compared to other navigation and positioning systems, GPS systems possess the special characteristics below:

1) Continuous Global Coverage. Due to the number of GPS satellites being relatively large and their distribution being rational, at any point on the globe, therefore, it is possible in all cases to observe at least 4 satellites continuously and synchronously, thereby guaranteeing global, all weather, continuous, real time navigation and positioning.

2) Multiple Functions and High Precision. GPS is capable of continuously supplying, for various types of users, three dimensional position, three dimensional velocity, and time information associated with dynamic targets. The single point real time positioning precision is capable of reaching 5-10m. Stationary relative positioning accuracies can reach 1-0.1ppm. Speed measurement accuracies are 0.1m/s. Moreover, time measurement precision is approximately a few tens of ns.

3) Real Time Positioning Speeds Are Fast. Making use of GPS systems, one iteration of positioning and velocity measurement operations can be conveniently completed within one to a few seconds.

4) Counter Jamming Performance Is Good and Security is Strong. Due to GPS opting for the use of special code technologies associated with digital communications, that is, pseudo random noise code technology, signals sent out by GPS satellites thus possess good counter jamming characteristics and security.

However, certain limitations also exist associated with the utilization of GPS systems. First of all, GPS receivers must directly "see" satellites. This poses limitations in urban areas or tropical forest regions. The low power microwaves GPS sends out are capable of penetrating glass or plexiglas. However, they are not capable of penetrating other common materials. In urban areas, signal feedback on building surfaces increases coverage. However, it makes precision drop. In tropical forests, trees will severely cover up signals. In situations where leaves are wet, this is even more the case.

## 1.2 GPS Policy

### 1.2.1 SA and A-S Policies

GPS supplies two types of precision services. Precision positioning service (PPS) makes use of P/Y code. It only serves the military departments of the U.S. and its allies. Standard positioning service (SPS) makes use of C/A code. It is open to the whole world. In order to prevent utilization by foreign subscribers and exploitation of the military capabilities of GPS, the U.S. has opted for the use of a number of limiting measures.

SA is a plan to "have selective availability" announced by the U.S. government in 1988. On the basis of this plan, there are artificially inputted errors in C/A code signals. When implementing SA, SPS precisions drop. Horizontal errors are 100m(2dRMS). Vertical errors are 156m(2 $\delta$ ).

A-S policy is used in order to fight electronic deception. If the enemy knows the frequency and phase of satellite signals being



received at user antennas, it is then possible to make use of /58 carrier waves with a certain transmission power and appropriate frequency as well as time code phases in order to make receivers wrongly lock on to signals, producing erroneous navigational position information. Due to the fact that the structure of the secret P code has already been broken, it is basically placed in a state of semi public disclosure. In order to prevent electronic deception, GPS goes through encryption, taking P code and transforming it into Y code. Therefore, A-S is not directly used in order to lower positioning precision. However, after the addition of A-S, unauthorized users then have no way to receive Y code signals, thus lowering positioning accuracy.

In the latter part of the 1980's, the U.S. launched Block II satellites on which selective availability (SA) began to be used. In 1993, the beginning of the use of counter electronic deception (A-S) was discontinued. After it is spread throughout the entire satellite constellation, its initial utilization will be continued.

What needs to be stressed is that the U.S.--in precision control policies--has clearly indicated that the errors introduced by SA are variable. In peacetime, only standard errors are introduced. Once U.S. forces are clearly threatened by enemy weapons assisted by the use of GPS, the U.S. President can order the increase of SA errors which may possibly very, very greatly exceed the 100m associated with peacetime SPS activities. At the present time, all users who are permitted to opt for the use of high precision operational forms--excluding a need for precision measurement (P/Y) decoding chips--still require a "precision positioning system security module" in order to eliminate the effects of SA. After the introduction of SA and A-S, system positioning precisions are as shown in Table 1.

Table 1 System Positioning Precision After Addition of SA and A-S

① 工作方式		② 授权用户		③ 非授权用户	
SA	A-S	P(Y)	C/A	P	C/A
④ 无	④ 无	16m	30m	16m	30m
⑤ 有	④ 无	16m	30m	72m	76m
④ 无	⑤ 有	16m	30m	30m	30m
⑤ 有	⑤ 有	26m	30m	76m	76m

Key: (1) Operating Method (2) Authorized Users (3) Nonauthorized Users (4) No (5) Yes

All of the above are calculated using spherical error probability (SEP). 76m DEP is approximately 100m(2dRMS) horizontal error.



### 1.2.2 Policy Trends

At the present time, the U.S. government is in the process of examining GPS policy to include civilian or military control with regard to GPS, technical policy making, macrozonal difference GPS, as well as policy on the collection of fees, and so on.

As far as the implementation of GPS fee collection is concerned, there is a need to add a number of measures on satellites in order to make users who do not pay fees have no way to make use of GPS signals. However, neither satellites that are launched at the present time nor those in orbit have this function.

With respect to satellites launched from now on, there is a possibility of adding this kind of function. The lives of satellites operating at the present time are all 10 years or more. Replacing them one by one requires a certain time period. Therefore, the previously promised 10 year no fee service may be extended to 20 years or over. Even if a fee collection policy is implemented, it can still be accepted by users. Moreover, if fees are collected with respect to GPS, it can achieve a certain assurance for its availability in terms of political causes. From now on, control in regard to GPS may possibly appear as a combined responsibility of the Department of Defense and the Department of Transportation in a situation where the Department of Transportation is in primary control. However, during war, the rights of control may be changed somewhat. With regard to halting GPS operations or removing GPS-SPS service, the U.S. has promised that it will make notification beforehand at least 6 months prior.

### 1.3 Difference GPS (DGPS)

Opting for the use of difference GPS technology can effectively resolve the problem of making C/A code precisions drop after the introduction of SA. As a result, difference GPS technology has been a subject of research competition between various nations of the world in recent years. Difference GPS certainly does not hurt benefits to the U.S. The U.S. has no need for and no way to limit research and applications associated with difference GPS.

What is called difference GPS is nothing else than taking a reference GPS receiver unit and putting it at a spot where the location is already precisely determined. Comparisons are made between the positioning data produced by this GPS receiver unit and the reference location, solving for the GPS system position for the point in question or the pseudo range measurement error. Then, these error values are taken and broadcast out through a transmitting station (difference station). Error signals coming from the difference station and received by GPS users in the vicinity calibrate their own GPS measurement values. Results from difference value experiments made domestically and abroad clearly show that, opting for the use of this type of technology, it is possible to cause subscribers making use of C/A code to basically eliminate the influence of SA within regions in the vicinity of the reference station, achieving the same types of precisions as opting for the use of PPS.

Applications of difference GPS do not solely depend on increasing positioning precisions. In regard to the basic problem with the use of GPS--the problem of independence--it is an important means of compensating and is one of the best methods to deal with SA policies. If cruise missile launch vehicle navigation systems opt for the use of difference GPS, even if use is made of C/A code receivers, it is still possible to make navigation system precisions achieve very great increases, thereby breaking free of SA policy limitations.

Synthesizing the analyses discussed above, it is possible to see that, despite the fact that the U.S. has set down a good number of measures to carry out controls in respect to GPS, it is, however, still possible to make use of this system. In this realm, we should track the newest development trends associated with foreign receiver equipment--in particular, intensifying research on applications of difference GPS.

#### 1.4 Foreign GPS Receiver Development Dynamics

With respect to cruise missile launch vehicles, GPS is primarily the taking of GPS receivers and using them in composite vehicle navigation. As a result, the focus of research is on such aspects as the selection of receiver models, the set up of receiver antennas on vehicles, as well as developing software to increase receiver C/A code measurement precisions.

1) Due to the U.S. opting for the use of SA policies, C/A code pseudo range measurement precisions went down. As a result, developing technologies to increase C/A code pseudo range measurement precisions has already become an important topic of research. According to reports, foreign scholars have done studies on a type of high precision C/A code pseudo range determination technique. The key is designing dual delay lock loop (DLL) discriminators for receivers. Test results clearly show that Nov Atel GPS receivers opting for the use of this type of technology to make use of C/A code pseudo range measurements can achieve P code pseudo range measurement precisions.

2) Developing GPS receiver azimuth determination functions is another direction in foreign GPS receiver development. At the present time, there are already several types of designs in development and testing. On the basis of a contract with the U.S. military engineering and mapping research institute (ETL), the Adroit systems company successfully developed a type of attitude determination system (ADS) based on GPS carrier wave signal interference. The system in question opts for the use of unique three antenna, dual base line designs. The technological key is to possess unique periodic resolution capabilities. The entire system sits in a machinery case. The structure is compact and handy. U.S. forces test measurement results with regard to prototypes clearly show that system azimuth measurement precisions are 1.2mill(0.0675°) on average. This system can not only be used as an aiming device, it can also be used for vehicle navigation. The advantage in making use of GPS to carry out direction finding is that there are no drift influences such as those associated with inertial reference systems. Thus, it is possible to further

increase weapons system combat capabilities.

3) In order to adapt applications of difference technologies, at the present time, GPS receivers developed abroad possess difference functions for the most part. In 1993, the U.S. Tianbao (Celestial Treasure) navigation company developed a light model portable GPS receiver. The antenna and receiver are sealed together in a sturdy casing with a smooth outer surface.

The Russian inertial science and technology center procured GPS receivers and inertial system components from the U.S. Trimble Co. and developed a set of processing software to receive C/A code themselves. They are capable of making positioning precisions increase from 80m to 15m.

#### 1.5 Current Status of Foreign GPS Military Uses and Future Requirements

At the present time, U.S. Army missile systems still have not made use of GPS in initialization, navigation, or supplementary navigation. However, 7 types of receivers such as VSN-8 (portable) light model GPS receivers (SLGR) and so on have already been successfully applied during Desert Storm activities. These receivers are "pazi (phonetic)" and play an important role in the initial calibration of this type of inertial guidance system. At present, the U.S. Army is in the midst of discussing how to take GPS and use it in missile carrier vehicle or launch vehicle navigation. They are in the process of setting up ways to take GPS receivers and merge them with the launch system radars associated with Patriot missile systems, using them for positioning. The earliest thinking was to make use of VSN-8 receivers. A final selection was made of medium precision light model GPS receivers (PLGR). This strengthening measure causes Patriot missiles to then be capable of realizing their own positioning on unreliably surveyed ground. Besides this, consideration is also being given to improving the fire control systems of multiple rocket launcher systems, using GPS receivers for positioning, assisting inertial ground navigation systems, and, in conjunction with this, supplying automatic azimuth calibration.

As far as the 1058 model vehicle navigation system developed by the Telidain-Ruian (phonetic) electronics company is concerned, option is made for the use of modularized design. It is capable of taking inertial navigation systems and combining them with GPS receivers and is used in the navigation of various types of military wheeled and tracked vehicles. The Sagem Company's Sigma 30 ring shaped laser gyroscope navigation system is capable of being combined together with the same range finders. It is also capable of being combined with GPS receiver systems. GPS makes Sigma 30 capable of independently acting as an azimuth and attitude indicator.

The U.S. Army missile command projects a need for a type of roughly general purpose P/Y code receiver, requiring it to be smaller, lighter, and less expensive than vehicle borne receivers and capable of being used in tactical missiles such as ATACMS. In this application, ATACMS missiles are launched from tubes. Before launch, direct tracking GPS navigation is not possible. As a

result, on launch vehicles, consideration is given to mounting P/Y code receivers in order to facilitate supplying the needed data through data trunk lines to missile receivers. Table 2 gives the expected characteristics by missile command with respect to projected tactical missile GPS receivers.

Table 2 Projected GPS Receiver Characteristics

Parameters	Tactical Missile Receivers	FOG-M Receivers
Minimum Channel No.	5	5
Acceptable Supplements	IMU and/or Barometer	IMU and/or Barometer
Dynamic Bearing Capability	15g (longitudinal) 10g (transverse) 10g (normal)	4g
Minimum TTFF	1 min	1 min
Maximum Volume (Missile)	410 cm3	82 cm3
Maximum Volume (Launch System)	No Details	1639 cm3
Maximum Mass (Missile)	0.9kg	0.11kg
Maximum Mass (Launch System)	No Details	1.8kg
Maximum Power Consumption (Missile)	5W	1W
Maximum Power Consumption (Launch System)	No Details	10W
Connections (Missile)	RS422A/423A and RS1553	50Ω SMA
Connections (Launch System)	RS422A/423A and RS1553	RS422A/423A and RS1553

## 2 COMPOSITE NAVIGATION

With regard to the main technical requirements associated with missile launch vehicle navigation systems, they are rapid positioning and direction finding in a precise manner, good independence, strong adaptability, and moderate prices.

GPS systems are capable of supplying high precision, real time positions and velocity data. However, GPS receiver counter jamming capabilities are relatively bad. Reception "windows" and terrain masking can easily effect them. When it is necessary to obtain continuous missile launch vehicle position, velocity, attitude, and control information, it is inappropriate to rely only on GPS. One effective way to resolve this problem is to take GPS systems and



low cost, moderate precision inertial navigation systems and carry out a synthesis.

As far as missile launch vehicle automatic positioning and direction finding systems opting for the use of inertial/GPS composite systems is concerned, it makes it possible to utilize the cumulative errors associated with GPS (difference GPS) position and velocity information to calibrate inertial navigation systems, standardize inertial components, and can, with the assistance of GPS, realize alignment and realignment on moving bases, shortening aiming time and not adversely affecting opportunities for combat. In particular, when crossing through regions where the terrain is not known in detail, GPS measurement values are especially important. Moreover, making use of inertial guidance system signals to act as supplementary information, it is possible to improve GPS receiver counter jamming capabilities in environments of strong enemy jamming signals. When GPS signals are interrupted, inertial navigation systems are still capable of continuing to operate.

Various tests as well as actual use carried out of inertial/GPS composite systems clearly show that this type of system is capable--in almost all field conditions--of satisfying requirements associated with dynamic positioning, direction finding, and velocity measurement indices posed by land navigation.

As compared to opting for the use of pure inertial guidance systems, this type of composite form possesses such advantages as high precision, good reliability, low cost, strong adaptability, good fast reaction characteristics, as well as a capability of opting for the use of modularized design, and so on. It is the main development direction associated with foreign military vehicle guidance systems at the present time. [Page 61 is missing.] /62 ...navigation accuracies of inertial navigation systems which belong to the high precision, quick connect inertial navigation systems are lower than platform type inertial navigation systems. However, they are higher than gyroscopic compass navigation systems. GPS system positioning precision, of course, belongs to the high precisions.

Table 4 sets out situations associated with various types of navigation systems utilized on missile vehicles.

With respect to any type of navigation system, increasing navigational precision means increasing cost. In regard to missile launch vehicles--while satisfying the precision requirements--lowering costs as much as possible is certainly the objective sought after. The influence on costs of increases in the navigational precision of gyroscopic compass navigation systems is very great. Moreover, missile launch vehicles also simply must require that precision be relatively high, thereby very, very greatly increasing costs. Inertial navigation systems are capable of giving higher navigational accuracies. However, costs are also very high. As far as quick connect inertial navigation system navigational precisions are concerned--although they cannot compare to platform type inertial navigation systems--due, however, to the

fact that they do not include stable platforms and need computers and computer programs, as a result, they can be made even smaller in volume and lighter in mass. At the same time, operations are more reliable. If it is possible to drop costs further, it can be hoped that, hereafter, applications will become more and more numerous. GPS receiver independent positioning precision is very high. Due to the fact that the direction finding functions are still in the development and test production stage, as a result--with regard to missile launch vehicle navigation--they are still only capable of acting as supplementary navigation systems to increase the positioning precision.

As far as applications of automatic positioning and direction finding technology on missile launch vehicles is concerned, although many reports have been seen, there still, however, have not been many applications on cruise missile launch vehicles. There are a few tens of types of cruise missiles in the world. With regard to ground based launch models, there are still only something over ten types. Among these, many opt for the use of fixed launch or semimobile type launches. There is no need for or no excessive demands on launch vehicle automatic positioning and range finding. There are only those cruise missiles opting for the use of field mobile launch methods where there is then a requirement for automatic positioning and range finding. Due to the fact that cruise missiles do not have such high requirements with regard to mobility characteristics as do ground to air missiles, as a result, option is made for the use of medium precision positioning and direction finding systems (Positioning accuracy is 0.2%-0.6% of distances. Direction finding accuracy is 1-3mil.) and that is all. In this connection, gyroscopic compass and inertial missile navigation systems are all capable of suiting this precision requirement. Moreover, inertial guidance systems like "pazi (phonetic)" as well as quick connect inertial navigation systems--as a function of lowering the costs--will be made wide spread use of in the automatic positioning and direction finding of cruise missile launch vehicles. Combinations of these systems and GPS receivers are then capable of further increasing positioning precisions, reliability, and adaptability--suiting the requirements associated with the development of cruise missile launch vehicle automatic positioning and direction finding systems.

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